MODELLING AND ANALYSIS OF SOME REAL LIFE APPLICATIONS USING QUEUING SYSTEMS

A SYNOPSIS

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MODELLING AND ANALYSIS OF SOME REAL LIFE APPLICATIONS USING QUEUING SYSTEMS

1. Introduction

Queuing theory is a branch of mathematics that studies how lines form, how they function, and why they malfunction. Queuing theory examines every component of waiting in line, including the arrival process, service process, number of servers, number of system places, and the number of customers which might be people, data packets, cars, or anything else.

Real-life applications of queuing theory cover a wide range of businesses. Its findings may be used to provide faster customer service, increase traffic flow, improve order shipments from a warehouse, or design data networks and call centres.

Structure of the Queuing Model

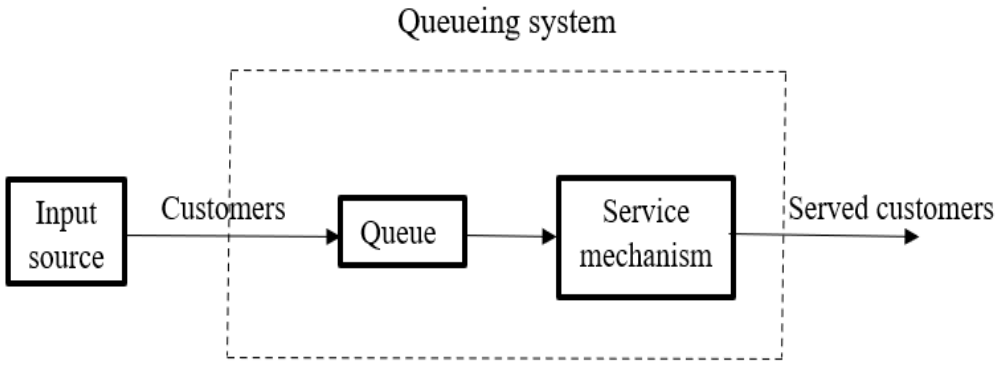

Figure 1.1 Basic Queuing Model

A Queuing model in a defined queuing system is elaborated in figure 1.1

Queue Discipline

The following disciplines are possible:

- If the system is filled to capacity, the arriving unit is rejected.
- **Balking** - a customer does not join in the queue.
- **Reneging** - a customer joins the queue and subsequently decides to leave.
- **Collusion** - customers collaborate to reduce waiting time.
- **Jockeying** - a customer switching between multiple queues.

Arrival pattern of Customers

Arrival describes how clients enter the system. Arrivals are mostly random, with unpredictable intervals between two neighbouring arrivals. The arrival is often defined by a random distribution of intervals, also known as the arrival pattern.

The reaction of a customer upon entering the system is also necessary to be known. A customer may decide to wait no matter how long the queue becomes or if the queue is too long, the customer may decide not to enter the system. In this case, the customer is said to have balked. On the other hand, a customer may enter the queue but after sometime lose patience and decide to leave. In this case, the customer is said to have reneged. In case, if there is more than one queue, customers may switch from one to another that is jockey for position. The above situations are examples of queues with impatient customers.

Service Pattern of Servers

The number of services per unit time or by the time required to service customer describes the service pattern. If the system is empty, the server is idle. In such situations the server may leave the system for a random period of time called vacation. These vacations may be utilized to perform additional work assigned to the servers.

Service Facility

- The service facility can have none, one, or multiple servers.
- Multiple servers can be parallels, in series (tandem) or both.

Queue Discipline

It is a rule by which customers are selected for service when a queue is formed. The most practiced queue discipline is first in first in out (FIFO). Others, including last come first serve (LCFS), random and priority service.

System Capacity

It introduces natural boundary queueing systems. In life system, there are only limited numbers of resources such as computer memory or network buffers. In queueing networks, nodes with finite system capacities may block customers from the previous node, when the node's capacity limit has been reached.

Service Channels

The number of service channels refers to the number of parallel service stations which can provide identical service facilities to the customers simultaneously.

Stages of Service

A service may have several stages. There may exist a series of service stages through which each customer must progress prior to leaving the system. They are called tandem queues. In practice, there exist a lot of situations, which can be modelled by complex queueing systems with service stages or simple computer networks.

Little's Formulae

One of the most important relationships in queueing theory was developed by John D.C. Little in the early 1960's. Little's law states that "the average number of customers in a system is equal to their average arrival rate, multiplied by their average time in the system". That is L = λ W.

From the above, Operating characteristics of a queueing system such as Queue Length (L_q), System Length (L_s), Waiting time in the queue (W_q), Total time in the system (W_s), Utilization factor (or) Traffic Intensity ρ are calculated.

Poisson Distribution

It involves the probability of occurrence of an arrival. The mean arrival rate (i.e., number of arrivals per unit of time) λ is assumed to be constant over time and is independent of the number of units already serviced, queue length on any other random property of the queue. Probability of an arrival in time $dt = \lambda\, dt$.

Exponential Distribution

It involves the probability of completion of a service. Mean service rate μ is assumed to be constant over time and independent of number of units already serviced. Probability that a service is completed between t and $t + dt = \mu\, dt$.

Non-Markovian Queueing Model

Consider models where the distribution of the inter arrival time or the service which do not possess the memory less property, i.e., are not exponential. The process {N(t)} giving the state of the system size at time t will then be no longer

Markovian; however, the analysis of the process can be based associated process which is Markovian.

Description of the M/G/1 and $M^{[X]}$/G/1 System

The M/G/1 model assumes that the Queueing system has a single server and a Poisson input process (exponential inter arrival times) with a fixed mean arrival rate λ. Customers have independent service times with the same probability distribution. No restrictions are imposed on the specific service time distribution. $M^{[X]}$/G/1 Queueing system differs from the above model only in the arrival. In this system, customers arrive to the system in batches of variable size. These models have been extensively due to its wide applications.

Bernoulli Feedback

The Bernoulli distribution is the simplest discrete distribution. It is used to model experiments with two possible outcomes, such as success/failure or yes/no. The possible outcomes of the distribution are $n = 1$ (success) with probability p, and $n = 0$ (failure) with probability $q = 1 - p$ where $0 \leq p \leq 1$.

Service Interruption

A service interruption (outage) occurs when you lose access to your subscribed resources running on the computer platform due to failure of a critical component of the service, including: virtual server, server instance, firewall, load balancer, switch, storage platform, and connectivity from the service platform to Communications network services. Moreover, in manufacturing systems, the machine may breakdown due to machine or job-related problems, in computer systems besides the scheduled backups. Server breakdowns result in a period of unavailable time until it is repaired. The breakdowns and the repair time could follow exponential, general, deterministic etc. distributions. A queue with two servers and random breakdowns was studied by Madan, Abu-Deyyed and Gharaibeh (2003a). Gray, Wang and Scott (2004) studied a queueing model with multiple breakdowns requires a finite random number of stages of repair.

In queueing systems, available of server at all time in the system is not possible in real life. The server may be leaving for a vacation, under repair, stopped for maintenance, attending to other queues. The different types of vacation models are

single vacation model and multiple vacation models. In single vacation, if the server comes back from the vacation, it does not go for another vacation even if the system is empty. In case of multiple vacation models, on return of vacation, the server starts service only if it finds n or more customers waiting in the queue. If the system is empty, again the server goes for vacation. The vacation time could be exponentially distributed or has general distribution.

Methods for Solving Queueing Models

One of the methods used for solving Markovian queueing models is to build up a difference-differential equation. There are several methods for the solution of equation of this type. The simplest method, which is applicable only in very special cases to solve recursively. Usually, the best method to deal with such equations is to convert them, if possible, into a single equation for a generating function. This method is discussed in detail by D.R Cox and H.D. Miller. Cox has analysed non- Markovian models by converting them into Markovian models through the introduction of one or more supplementary variables.

2. Literature Review

Only at service startup, the setup time stage in the queuing system has been examined by several authors. That happened at the start of the first service. However, if the system has numerous service levels, setup times between the levels will also be necessary so that the pre-processing necessary for the following service level can be completed.

A non-Markovian queue with incongruent arrivals was thoroughly investigated by Badamchi Zadeh and Ghahramani [1]. Ayyappan G and Nirmala [4] carried out an analysis on a non-Markovian queuing model with customer impatience for the mass service queuing system with setup time and vacations. Gautam Chodhury and Lotfi Tadj [5] carefully considered the possibility of having two periods of administration over an $M^X/G/1$ unreliable server line. Performance metrics for a $M^{[X]}/G/1$ queue with optional third-level service and deterministic server vacations were derived by Madan [6]. Using a queuing approach, Maragathasundari Sand Dhanalakshmi K S [7] looked into the issue of ad hoc mobile networks. Sathiya K and Ayyappan G [8] established a Non-Markovian Batch Arrival Queue with Administration Interference Lining model. The supplementary variable technique (SVT) for single-server non-Markov queues

with service interruption was thoroughly explained by Jain et al. [9]. In a multi-server queuing system, Kadi et al. [10] investigated the impact of impatient customers and multiple vacation policies. In detail, the optimisation algorithm for resolving systems of singular boundary value problems was discussed by Abo-Hammour et al. [12]. In the context of breakdown services, Rajadurai et al. [14] conducted a performance analysis of an M/G/1 repeat queue with feedback. The study of general service distribution with a setup time and optional second administration was reviewed by Maragathasundari S [15]. Maragathasundari S and Manikandan P [17] performance metrics for a long vacation queue system and optional service types were derived. Maragathasundari S and Srinivasan S [18] looked into multi-stages of service in a non-Markovian batch queuing system. Optional services in a non-Markov queue have been thoroughly studied by Maragathasundari S and Srinivasan S [19]. The two-stage queue vacation model $M^{[X]}$/G/1's time-dependent solution was derived by Shyamala and Vijayaraj in [23].

In addition, the notion of reneging is one of the more recent additions to the boundaries that is inevitable in the reality of lining framework. Many analysts have looked into vacation models with clumpy appearances in-depth. Another endeavour being pursued at the moment is reneging during getaways in a lining framework. In addition, setup time organisation has just recently been added as a parameter. The non-Markovian single server group appearance queuing arrangement of mandatory administrations and administrative interference was studied by Vignesh P and Maragathasundari S [25].

3. Objectives and Scope

Literature on Queueing Theory lacks studies conducted in depth on queues with server vacation, random breakdown and the concept of reneging. A very little of the earlier work considers both vacation and breakdown in the system and these published papers rely on different assumptions than those considered in the current study.

In our thesis, the most important non-Markovian queueing models M/G/1 queueing system and M[x]/G/1 queueing system are taken into consideration. Single arrival and batch arrival are considered. Arrival follows a Poisson distribution. No restrictions are imposed on service time distributions. So, it follows a general distribution. Batch arrival is the arrival coming in groups (or) the service is rendered

in groups. The size of the groups' will be as a random variable given by probability distribution.

In the earlier work of our researchers, on non-Markovian queue, single vacation was considered to a great extent rather than a multiple vacation. Also, service is given only in a particular stage. Multi stages of service, Phases of service and types of services have not been taken for study. Moreover, Optional service is given but it is limited to a single.

While in the current study of our models, we assume $M^{[X]}$/G/1 queueing model of two stages of service and multi stages of service with reneging. Also, M/G/1 queueing models based on assumptions that three stages of service with compulsory vacation, multi-server vacation, breakdown and repair are taken into consideration. Stages of service and phases of service are the different assumption considered in our models differs from the earlier work. The usage of earlier models in industries, factories, communication networks is minimum and very limited. But the models in our current plays a vital role of rendering maximum usage in large scale industries, factories of maximum production and big network of communication. Phases of service and types of service are the added features which makes the service efficient and minimize the waiting time of the customers in the system. This leads to the complete satisfaction of the customers.

This study is conducted with the following objectives:

- Investigation of Queuing model in three stages of service with setup time stage and interrupted breakdown.
- A study on a Non-Markovian Queuing model in two types of reneging process and vacation with different stages of service.
- Analysis of $M^{[x]}/G/1$ Queuing model with feedback service and compulsory vacation.

The Queueing models investigated in this research work can solve many practical situations that occur in a system such as, where the servers are not continuously available for providing service for arriving customers; server is under Breakdown and at the time of customer's reneging. These results provide detailed information for large scale industries, communication networks and other fields in which the need to take decisions on systems having queues is essential. Consequently,

we expect that our study will greatly help system designers in their decision regarding the system parameter and that this work provides new knowledge in queueing theory.

4. Research Problems

In our work, we deal with the research problem as follows:

- Examination of a single server batch arrival non-Markovian queuing model method to foot thermogram classification.
- Queuing system dynamics in Thermo pack production.
- Supervisory control and data acquisition (SCADA) system's assessment.

The above problems are discussed in various chapters in our thesis. Our model plays a major role in multi-tier applications in foot thermograms, thermo pack production and Scada system.

A brief explanation of our problems in the form of chapters described in our thesis is given below:

Chapter 1: In this chapter, description about the newly defined queuing system characteristics in the problem is studied.

Chapter 2: The batch arrival queuing model with three stages of service of service interruption and repair process is discussed in detail

Chapter 3: In this chapter we discuss about the non-Markovian model including two times occurring reneging process of this stage is investigated

Chapter 4: The new strategy of feedback service and Compulsory vacation in general distribution queuing problem is solved.

The defined Queuing issues are addressed using the supplementary variable approach, and the relevant performance measurements are generated.

5. Organization of Thesis

CHAPTER – 1: INTRODUCTION

1.1 Non – Markovian queuing model [(M/G/1): Model]

We consider a non-Markovian queuing model, namely the (M/G/1) queuing system, i.e., we consider the queuing model with Poisson input, general output, single server with infinite capacity and general service discipline. We note that for this non-Markovian model, the distribution of the service time does not possess the memoryless property, i.e., it is not exponential. Thus, the process {N(t)} which provides the number

of customers at time t (or the state of the system or system size at time t) will be no longer Markovian. However, the analysis of the process can be carried out on an associated process, which is Markovian. Kendall used the concept of regeneration point by suitable choice of regeneration points and extracts, from the process {N(t)}, Markov chains in discrete time at those points. This is called the technique of imbedded Markov chains.

We shall carry out our analysis of (M/G/1) Queuing system by using Kendall's method. Here, we consider a single-server queuing system with infinite capacity, Poisson arrivals and general service discipline. The model has arbitrary service time and it is not necessary to be memoryless

1.2 Queuing System Characteristics

1.2.1 Setup time Stage

Setup time plays an important role in the investigation of lining frameworks, which is defined as follows: at the end of the busy time frame, the server enters an arbitrary arrangement time process before truly offering support to another client, or a group of clients joins the framework in the re-established occupied period.

i.e., Setup time is the amount of time required to configure a machine so that it is ready to perform a task. It is critical to reduce setup time for small production runs in order to engage in just-in-time production more easily.

1.2.2 Reneging

The point at which a person joining a queue, leaves without being served is usually considered as Reneging. The longer a client pauses, the more likely they will be disappointed.

1.2.3 Vacation

Vacation is defined as taking a break from your regular work to do any support work in the server to help reduce service interruption; similarly, any pre-handling work is to be done if it is required for the following phase of administration.

1.2.4 Stages of Service

The term "service channels" refers to the number of parallel service stations that are active at the same time. A client must visit a certain number of service stations in a row to receive full service. This is referred to as the service stages.

1.2.5 Compulsory Vacation

It is a set amount of time that employees or machines can take off from work, usually to relax and rejuvenate. Most employers or machines set a vacation time limit.

1.2.6 Feedback Service

Feedback analytics services use customer-generated feedback data to measure customer experience and increase customer satisfaction. Key performance indicators and feedback metrics are used to convert the feedback data collected into useful information that can be used to improve websites.

1.2.7 Server Interruption

Computer systems, communication systems, networks, and other systems can all fail at any time. Consider a machine that requires regular maintenance, particularly oil changes. If the machine runs out of oil, it will break down, necessitating the services of a repairman who will re-oil the machine.

1.2.8 Repair Process

Repair Services refer to the restoration of Equipment to its original function on an as-needed basis, as may be required by the Facility in response to such equipment's failure or malfunctioning. Servicing, reconditioning, modification, and refurbishment may also be part of the repair process.

Examples for such repairs are removing Chok age of drainage pipes, manholes, restoration of water supply, replacement of blown fuses, repairs to faulty switches, watering of plants, lawn mowing, hedge cutting, sweeping of leaf falls etc.

1.3 Supplementary Variable Method for Solving the Queuing Issue

When one or more random variables are added to convert a non-Markovian process to a Markovian process, the technique involved in this conversion is known as supplementary variable technique. This is developed by keelson and kooharian

The method of supplementary variables is a technique used in queuing theory to solve for the stationary distribution of an M/G/1 queue. David Cox and David George Kendall (1951) were the first to use it. Non-Markovian queues can be studied using either embedded Markov chains or the supplementary variable method. By adding one or more variables to the state space, the supplementary variable method aids the

Markovian process. This supplementary variable is a continuous variable. This results in a Continuous State Space and Continuous Time Markov process.

CHAPTER – 2: ANALYSIS ON FOOT THERMOGRAM CLASSIFICATION BY THE USAGE OF NON-MARKOVIAN QUEUING MODEL

2.1 Introduction

In this chapter we study a single server non-Markovian queuing model with Poisson arrivals in stacks of different sizes. With a general service time distribution, the server delivers three phases of services to all clients. To begin, the stage I service is provided by the server. Following that, the setup time stage is established to carry out the necessary preliminary work for the stage 2 service, and clients may cancel during the setup phase. Furthermore, the server experiences sporadic interruptions throughout the third stage of service and promptly begins the repair procedure. Customers finally depart the system after receiving stage 3 service. The effect of the setup time stage, interruption and reneging in the defined queuing system are well analysed. Using the supplementary variable technique of queuing theory, the duration of the queue length of different states of the system in terms of probability generating functions and the queue performance measures are determined.

2.2 Diagrammatic Representation of the Model

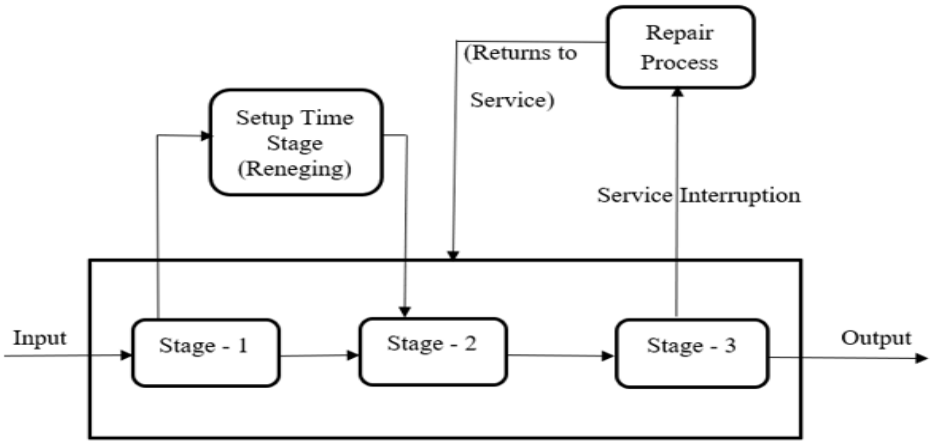

Figure 2.1 Diagrammatic Representation of the Model

A Queuing model of different stages of service with service interruption and setup time stage is represented in figure 2.1

2.3 Performance Measures of the Queuing System

A supplementary variable technique is used to solve the defined mathematical queuing problem and the corresponding performance measures for the system are derived.

The Probability generating function of the queue size is

$$P_q(z) = \frac{Q\lambda_k(C(z)-1)\left[\begin{matrix}\overline{M_1}(a)+\overline{M_1}(a)\left[\frac{1-\bar{D}(b)}{b}\right]+\overline{M_1}(a)\bar{D}(b)\left[\frac{1-\overline{M_2}(a)}{a}\right] \\ +\overline{M_2}(a)\left[\frac{1-\overline{M_3}(h)}{h}\right]+\beta z\overline{M_2}(a)\left[\frac{1-\overline{M_3}(h)}{h}\right]\left[\frac{1-\bar{L}(a)}{a}\right]\end{matrix}\right]}{z-\overline{M_1}(a)\bar{D}(b)\overline{M_2}(a)\left[\overline{M_3}(h)+\beta z\left[\frac{1-\overline{M_3}(h)}{h}\right]\bar{L}(a)\right]}$$

Using the Little's formula, to find the other performance measures,
The following measures are derived and calculated

- The idle time, $Q = 1 - P_q(z)$
- The utilization factor, $\rho = 1 - Q$
- The Length of the queue, $L_q = \lim_{z\to 1} \frac{d}{dz} P_q(z)$

Little's formulas are

- Average number of customers in the system $L = L_q + \rho$.
- Average waiting time of the customers in the queue $W_q = \frac{L_q}{\lambda_k}$
- Average waiting time of the customers in the system $w = \frac{L}{\lambda_k}$

2.4 Numerical study

2.4.1 The Effect of Completion of Repair process $\eta = 4,\ 4.6,\ 5, 5.4, 5.8$

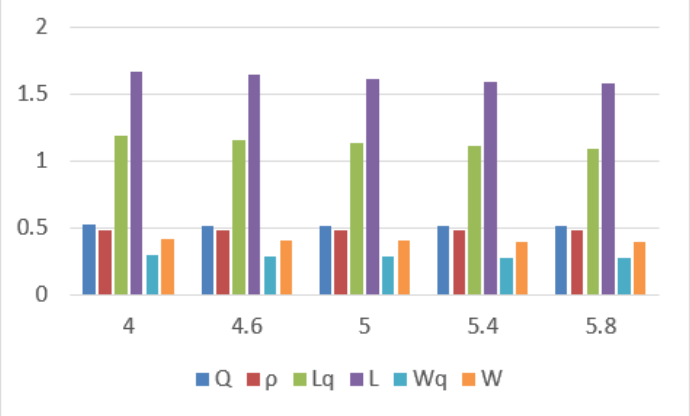

Figure 2.2 Effect of Repair process η

Figure 2.2 describes the concept of repair process. Since the server is down for various reasons, the server enters the repair process without delay. If the server is interrupted, the length of the queue often increases, leading to increased waiting time for clients in the queue and on the system. But here the server was able to resume its service more quickly as the repair rate was increased. The server spends more time serving the clients and helping them log out quickly. This reduces the waiting time for clients in the queue and in the system.

CHAPTER – 3: QUEUING SYSTEM DYNAMICS IN THERMO PACK PRODUCTION

3.1 Introduction

In this chapter we study a single server non-Markovian queuing system in which the customers enter the system and joins the queue. The server begins work with the setup time stage, during which the reneging procedure of phase I occurs. When that step is finished, it moves on to the next level of service. After the first stage, the server enters the vacation stage, which is when the idea of phase II reneging arises. Finally, the server entered the end stage of service. Customers leave the queue once they have received that service. Using the supplementary variable technique of queuing theory, the duration of the queue length of different state of the system in terms of probability generating functions and the queue performance measures are determined.

3.2 Diagrammatic Representation of the Model

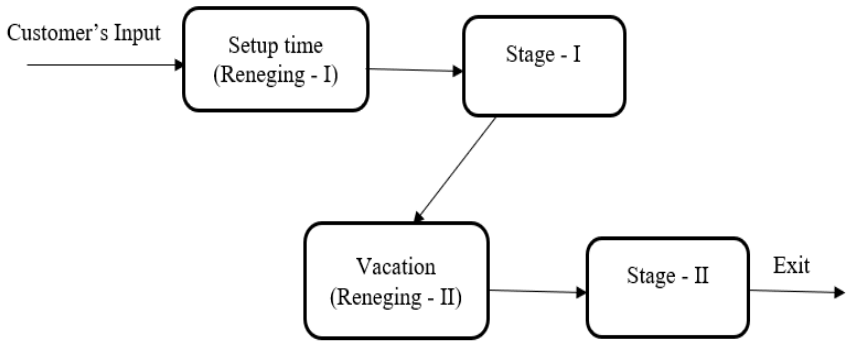

Figure 3.1 Diagrammatic Representation of the Model

Figure 3.1 gives a detailed description of a non-Markovian queuing system with different reneging phases.

3.3 Performance Measures of the Queuing System

A supplementary variable technique is used to solve the defined mathematical queuing problem and the corresponding performance measures for the system are derived.

The Probability generating function of the queue size is

$$P_q(z) = \frac{\lambda_k(z-1)\left\{\left[\frac{1-\bar{D}(a)}{a}\right]+m\overline{M_1}(b)\bar{D}(a)\left[\frac{1-\bar{F}(c)}{b}\right]\right\}-\bar{D}(a)[(1-\overline{M_1}(b))+m\overline{M_1}(b)\bar{F}(c)(1-\overline{M_2}(b))]}{z-m\overline{M_1}(b)\bar{D}(a)\bar{F}(c)\overline{M_2}(b)}$$

Using the Little's formula, to find the other performance measures,
The following measures are derived and calculated

- The idle time, $Q = 1 - P_q(z)$
- The utilization factor, $\rho = 1 - Q$
- The Length of the queue, $L_q = \lim_{z\to 1} \frac{d}{dz} P_q(z)$

Little's formulas are

- Average number of customers in the system $L = L_q + \rho$.
- Average waiting time of the customers in the queue $W_q = \frac{L_q}{\lambda_k}$
- Average waiting time of the customers in the system $w = \frac{L}{\lambda_k}$

3.4 Study on the effect of parameters in the defined queuing system

3.4.1 The Effect of Reneging $\xi_1 = 1.5,\ 2,\ 2.5,\ 3,\ 3.5$

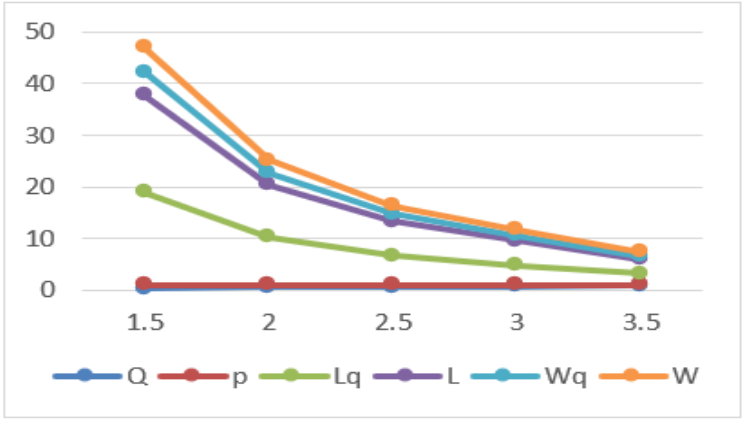

Figure 3.2 Graphical portrayal of the effect of Reneging

The process of Reneging is discussed in detail in the above Figure 3.2. Due to impatience, clients leave the framework during the server's get-away time. All the execution parameters L_q, L, W_q and W are decreased. Because of fewer clients, the usage factor diminishes and subsequently, the idle time Q of the server increases.

CHAPTER – 4: SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA) SYSTEM ASSESSMENT

4.1 Introduction

In this paper, we discuss about non-Markovian sequence model. Customer arrivals follow a Poisson process and service times follow a general distribution. A single server provides services to clients one by one. Customers log into the service. After completion of the service and if there there are no customers in the system, the server goes to compulsory vacation. After the vacation is over, the server resumes service. Customers that are displeased with the service rejoin the queue for a feedback service. To deliver the feedback service to consumers, the server enters the setup time stage, when all pre-processing work for the feedback service is accomplished. Finally, the consumers are served and they exit the system. The impact of mandatory vacation, setup time level, feedback service, and reordering in a finite sequence system has been thoroughly investigated.

4.2 Diagrammatic Representation of the Model

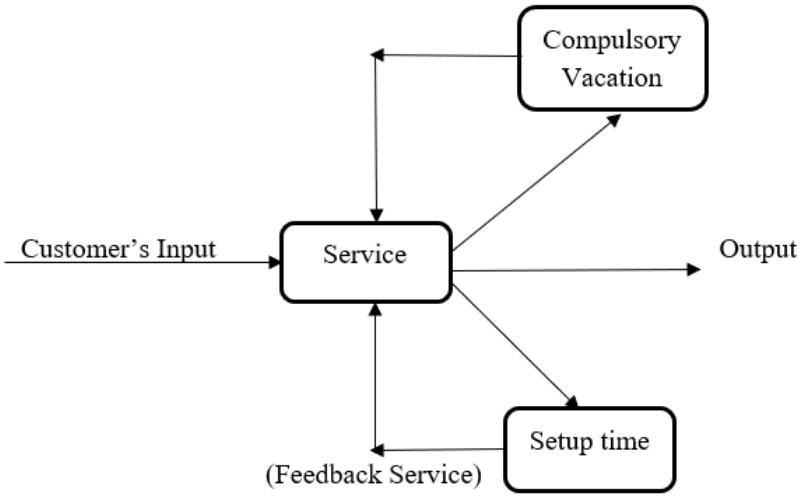

Figure 4.1 Diagrammatic Representation of the Model

The Queuing system defined in the SCADA scheme is explained in figure 4.1

4.3 Performance Measures of the Queuing System

A supplementary variable technique is used to solve the defined mathematical queuing problem and the corresponding performance measures for the system are derived.

The Probability generating function of the queue size is

$$P_q(z) = \frac{\lambda_k(C(z)-1)Q\left(\bar{M}(a)\left(1+\bar{F}(a)+\bar{F}(a)\bar{D}(a)\right)\right)}{z-\bar{M}(a)\bar{F}(a)[f\bar{D}(a)-m]}$$

Using the Little's formula, to find the other performance measures,
The following measures are derived and calculated

- The idle time, $Q = 1 - P_q(z)$
- The utilization factor, $\rho = 1 - Q$
- The Length of the queue, $L_q = \lim_{z\to 1} \frac{d}{dz} P_q(z)$

Little's formulas are

- Average number of customers in the system $L = L_q + \rho$.
- Average waiting time of the customers in the queue $W_q = \frac{L_q}{\lambda_k}$
- Average waiting time of the customers in the system $w = \frac{L}{\lambda_k}$

4.4 Discussion on the effect of Parameters

4.4.1 The Effect of Feedback Service $f = 0.1, 0.3, 0.5, 0.7, 0.9$

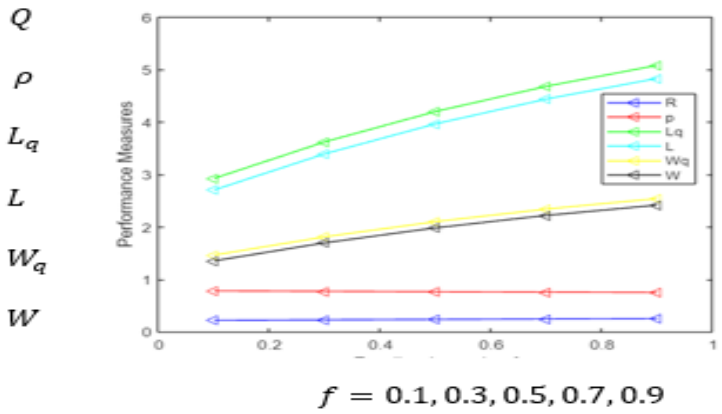

Figure 4.2 Graphical view of Feedback Service f

The concept of feedback service in the defined queuing system is clearly picturized in Figure4.2. The feedback service measures customer experience and improves customer satisfaction. If customers require a feedback service, then the queue length increases and the utilization factor decreases.

CHAPTER – 5: CONCLUSION

The probability generating function of the queue size is obtained for each of the aforementioned models. The average queue size, average waiting time in the queue, customer waiting time in the system, and total number of customers in the system have all been calculated as performance metrics. Each of the models just mentioned has a practical application. The simulation component is well addressed. The models mentioned are used in real-world situations. Queuing theory is used in a variety of disciplines and businesses, including health care, manufacturing, transportation, telecommunications, and service. Queuing theory may aid in the design and management of the capacity and flow of patients, workers, and resources in hospitals, clinics, and pharmacies.

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